The cathode lens mode of the SEM in materials science applications

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1. Introduction

The scanning electron microscope (SEM) represents a well-proved tool for observation and microanalysis of solid surfaces and thin surface films. When scanning the field of view with a focused electron probe and collecting some part of the emitted signals, we automatically ascribe the acquired information to the immediate coordinates of the primary beam. However, the full interaction volume from which the signal species are released is significantly larger than the size of the primary spot in the sample surface plane, which is usually considered to define the image resolution. The size of the information producing volume depends on the beam energy and at standard SEM energies it reaches units of micrometers or even more. Still, images at resolution similar to the spot size can be recorded but only when utmost surface-bound contribution to the image signal dominates enough. An example is the surface topography visualized by slow secondary electrons excited by primary electrons (so called SE1) within the tiny spot, with the SE2 signal, released by the backscattered electrons (BSE), coming from a spot so smeared that this contrast component is "dissolved" in the image background. However, at many instances the surface relief does not dominates, like when, for example, examining smooth flat surfaces with small localized inhomogeneities (inclusions, precipitates, etc.). In this case the image resolution deteriorates drastically. Another issue in the SEM practice are the usual signal detection principles that not only produce a mere single-channel data but even definition of these values, i.e. demarcation of the acquired energy and angular interval in the full distribution of the electron emission, is insufficient or even unknown. The cathode lens mode (the SLEEM – scanning low energy electron microscope) [1] enables one to decrease the landing energy of electrons while preserving the spot size, and modifies the conditions on which the signal electrons are collected so its materials science applications are worth of reviewing.

2. Experimental

The cathode lens (CL) is composed from the sample surface, serving as the cathode held on a high negative potential near to the potential in the SEM gun cathode, and an anode on the ground potential. Primary electrons are retarded in the CL field and impact the sample with a low energy given by difference of the two high potentials. Calculations showed [2,3] the main aberration coefficients, C_S and C_C, of the compound objective/cathode lens to be inversely proportional to the field strength inside the CL. In a standard SEM the spot size at low energies grows at least proportionally to $(\text{energy})^{-3/4}$ if the optimum beam aperture is adjusted at each energy, or to $(\text{energy})^{-1}$ at a constant aperture. With the CL this slope amounts at worst to -1/2 but can even be fully suppressed, providing hence an energy independent image resolution (Fig. 1).

The CL field accelerates all emitted electrons and, via increasing their axial velocity, collimates them toward the optical axis. Consequently, the anode plane is entered by a mixture of SE and BSE in a relatively balanced proportion given by the sample properties and the CL configuration. This signal flux exhibits an energy spread equal to the landing energy, with upper limit of the interval equal to the primary energy. Detection of this flux can be made by a variety of assemblies, in principle resembling the BSE detectors but regard is needed for the signal beam strongly condensed around the optical axis at a width diminishing with decreasing energy.

The examples presented here have been acquired in an SEM equipped with a CL in which the anode was formed by a co-axial bored disc from a single crystal YAG scintillator serving hence as the detecting element, too [1,4,5].

3. Results and discussion

Suitable examples demonstrating performance of the CL mode include structures with nanometer-sized inhomogeneities, prepared with a smooth flat surface. The Mg_xSi precipitates in the Al-1.0mass% Mg_2Si-0.4mass% Mg alloy (Fig. 2a,b) are not only much sharper observed in the SLEEM image but an advantageous mix of SE and BSE, an enhanced sensitivity of the BSE yield to crystallographic orientation, and favorable ratio between BSE yields of materials with similar atomic numbers enable one to distinguish at least two different types of precipitates, which later were found having different composition [5]. While for the previous case energy of 1600 eV was sufficiently low, the composite of MgB_2 particles in Al is best examined at mere 10 eV (Fig. 2c,d). In Fig. 3, a p-type doped pattern on n-type Si is shown at 1.5 eV only, when dynamic charging of the doped area to about 1 V secures the very high contrast due to total reflection of the beam onto or outside the detector.

References:

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[4] K. Matsuda, T. Matsuki, I. Müllerová and L. Frank: J. Electron Microscopy 54 (2005) 109-117.
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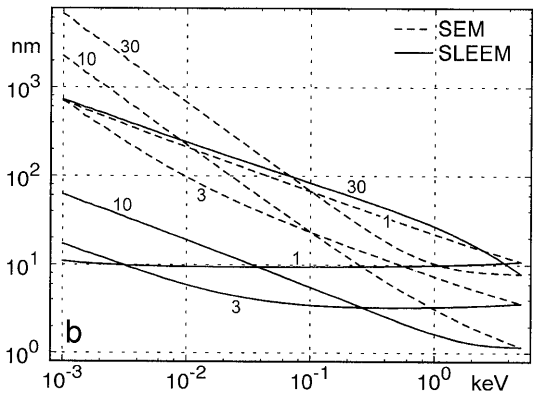

FIG. 1. Calculated spot sizes (C_S=1.6 mm, C_C=1.1 mm, FEG) labeled with the object-side aperture in mrad.

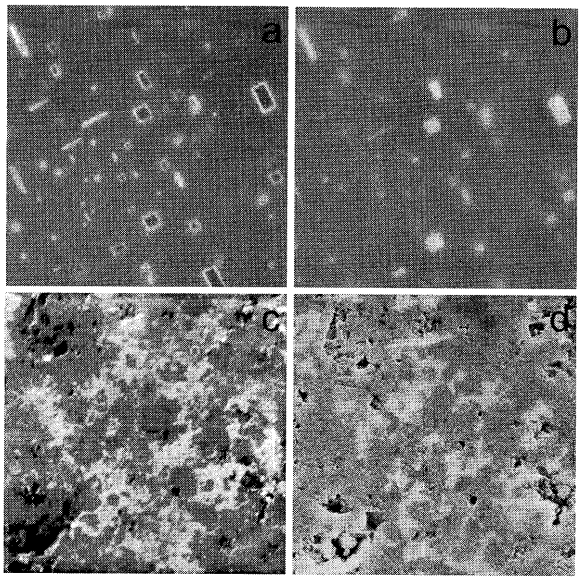

FIG. 2 (top right) Mg_xSi precipitates in Al-Mg-Si alloy at 1600 eV (a) and 10 keV (b) (field width 7 μm); MgB_2/Al composite at 10 eV (c) and 10 keV (d) (field width 14 μm).

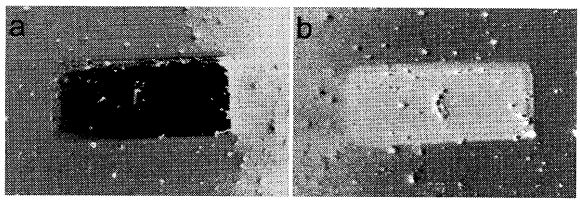

FIG. 3 (bottom right) A p-type area in n-Si, 1.5 eV, normal impact (a) and 0.72° tilt (b) (field width 50 μm).